CURATION PROTOCOL OF PHOBOS SAMPLE RETURNED BY MARTIAN MOON EXPLORATION (MMX).

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Introduction: The Martian Moons Exploration (MMX) aims to return the regolith samples from the Martian moon, Phobos. After the topographic and spectroscopic observation, the spacecraft will land on the surface of Phobos to conduct the sampling operation [1–2]. Pneumatic and coring samplers will collect ≥ 10 g Phobos grains from two different sites. The collected samples will be retrieved from the capsule and transferred to the curation facility in 2029.

Sample analyses for the Phobos grains are the key to achieving the MMX mission goals [3]. The mineralogy, petrology, geochemistry and isotopic compositions (e.g. O and Cr) of bulk-scale Phobos grains will, define the origin of Martian moons. Chronology using noble gases and moderately volatile isotopes will determine the timing of geologic events on Phobos. Organic chemistry is also a powerful tool for the origin of small bodies in the case of capture origin. In addition, grains from Mars, possibly incorporated into the Phobos samples, may be the first Martian samples collected by sample return missions.

The MMX's Sample Analysis Working Team (SAWT) designed the flow of the sample analysis of Phobos samples [4]. Before the sample analysis, Phobos samples will be stored in a clean glove box under purified N_2 condition, called the "clean chamber." The operation phase of Phobos grains within the clean chamber is termed "curation." The design of the curation protocol is critical for the sample allocation and subsequent sample analysis phase. Based on the knowledge of the preceding sample return mission of Hayabusa 2, MMX introduces a new concept of curation, that is, the cooperation of curation with the remote-sensing teams and interdisciplinary Science Strategy Teams (SSTs). This study reports the curation protocols and refined sample analysis flow defined by SAWT with the support of JAXA's curation team and MMX remote-sensing instrument teams.

Curation facility: The clean chamber for the MMX will be installed at the Astromaterials Science Research Group (ASRG) facility at ISAS, JAXA. The curation chamber will be equipped with the necessary instruments and tools for curation: e.g., balance, optical microscope, and FT-IR imager. The instrument teams (MIRS, OROCHI, MSA, and RAX) will cooperate with SAWT to develop the ground-based models of their instruments, which will be utilized in the curation and sample analysis phase.

Design of curation protocol in the nominal case: Figure 1 shows the total framework of the sample curation protocol in MMX. We assume 10 g for the whole sample amounts and 300 μm for the typical size of Phobos grains [5] as the nominal case. The curation protocol consists of three phases: 1) Quick Analysis, 2) Pre-basic Characterization, and 3) Basic Characterization. (1) First, we assess the degree of the leak of terrestrial air by collecting the gas filled within the sample container (Quick Analysis). (2) After collecting the container headspace gas, the sample corers will be introduced into the clean chamber. Subsequently, Phobos grains will be observed with an optical microscope, a visible multi-band microscope, and a near-infrared imager (Pre-basic Characterization). (3) Finally, the samples will be further investigated in the clean chamber, and an aliquot will be selected for the sample analysis team (Basic Characterization).

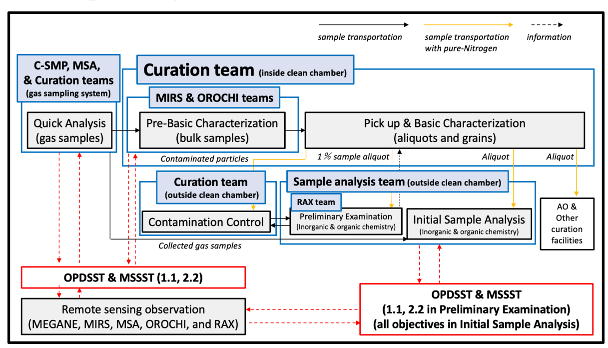

Fig. 1 Design of curation and sample analysis protocols for the Phobos grains.

Quick analysis. The objectives of the quick analysis are (1) Evaluation of the leak and contamination of the sample container and (2) Ground truthing of MSA data for the ions implanted into the Phobos grains. The quick analysis will be conducted by the gas extraction instrument equipped with a mass spectrometer. The techniques of the quick analysis will be based on GAs

Extraction and Analysis system (GAEA) in the Hayabusa2 mission [6]. The mass spectrometer will be developed in cooperation with the MSA instrument team. The headspace gas contains volatiles from different origins: the solar wind, the intrinsic volatiles of Phobos, the Martian atmosphere, and terrestrial air. The solar wind will be detected by the amount of He ($m/z = 4$), and the Martian atmosphere by the amount of CO ($m/z = 28$) and CO_2 ($m/z = 44$). In addition, any leak of terrestrial air into the container will be evaluated by the abundance of N_2 ($m/z = 28$). The results obtained in the quick analysis phase will be shared with SSTs.

The sample container will be introduced to the interface of the clean chamber, and the Phobos grains will be collected under the purified N_2 conditions.

Pre-basic characterization. The objectives of the pre-basic characterization are (1) Collecting Phobos grains safely from the sample canister, (2) Evaluation of contamination in the grains, (3) Ground truthing MIRS and OROCHI data, and (4) Obtaining the statistical information of Phobos grains. All the analyses in the pre-basic characterization will be performed within the clean chamber under purified N_2 conditions. First, we obtain the total weight of Phobos grains. The Phobos grains will be distributed in clean sample dishes after the weight measurements. Next, we will observe 2D infrared images of Phobos grains in the sample dishes by a FT-IR. The FT-IR data will provide the ground truth of MIRS measurements. Finally, a visible multi-band microscope will observe the bulk Phobos grains in the dishes. The OROCHI simulator or engineering model will be utilized for the curation process to see the ground truth.

Basic characterization. The objective of the basic characterization is the selection and detailed observations of samples allocated to the sample analysis team. All the investigations in the basic characterization will be performed within the clean chamber under a purified N_2 condition. First, a part of the Phobos grains will be split into about 20 aliquots. We will observe the infrared and visible spectra for the aliquots after the weight measurements of individual dishes. A representative dish (1% of total mass) among the 20 aliquots will be transported out of the clean chamber. After the preliminary examination, the sample analysis team will provide feedback to the curation team about detailed petrologic and chemical information. Based on the preliminary examination information, the curation team will select aliquots suitable for the scientific goals of the individual sub-teams (e.g., chemistry, petrology, organic chemistry) in the initial sample analysis team.

A framework of preliminary examination: The "preliminary examination" in the MMX mission was defined as the sample analysis and the curation protocols (within two months after the sample returns). The reason for performing preliminary examination was mainly for revealing the nature of the returned samples [4]. We refined the preliminary examination definition with the new design of the curation protocol. The objectives of the preliminary examination are (1) Providing feedback prior to the basic characterization, (2) Providing necessary information from the samples in a timely manner to help SSTs achieve the mission goals, (3) Evaluation of the effect of terrestrial alteration.

In preliminary examination, the necessary analyses to achieve the mission goals will be performed (Fig. 2). For instance, oxygen isotope measurements are essential for mission objective "1.1: *To determine whether the origin of Phobos is captured asteroid or giant impact.*" [2]. Therefore, IRMS and SIMS for aliquots of the Phobos grains will be performed in the inorganic chemistry flow.

Exploring Martian materials from Phobos grains is one of the most critical phases in the preliminary examination. Non-destructive analysis using FT-IR will be used to obtain the mapping data of the aliquots of the Phobos grains. FT-IR mapping aims to detect hydrous materials, carbonate, and organics. Raman spectroscopy can detect quartz, olivine, and carbonate. The direct comparison between RAX (a Raman spectrometer on the MMX Rover [7]) and their ground-based model allows us to distinguish the Martian minerals from Phobos grains.

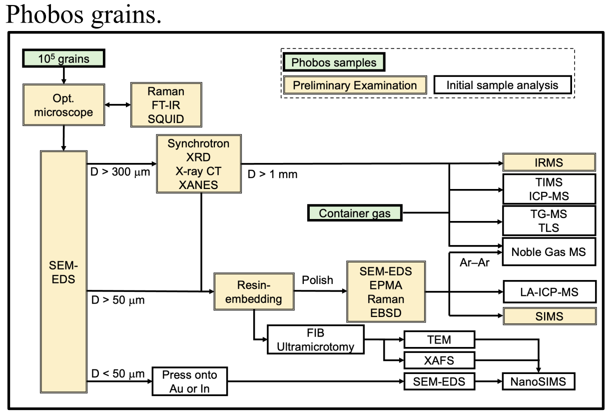

Fig. 2 Flowchart of the inorganic chemistry analysis in the preliminary examination and initial sample analysis.

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